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Analysis and Retrofit of the EEE Portuguese Recovery Network

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Abstract

The Portuguese directive 230/2004 established December 2006 as the dead-line for the legal targets of EEE recovery to be achieved. The EEE producers working in Portugal set up an organization whose mission is to design and manage this recovery network. A MILP model was previously developed to optimize the network design where, by considering EEE sources and recycling facilities locations as known, sorting centre locations were determined together with the planning of collection and sorting activities. In the present paper, the network planned by the Portuguese EEE organization is compared with the results provided by this early model. In addition, and taking into account new organizational objectives, where collecting and sorting entities should independently perform the associated activities, the developed model is further extended, in order to account for a new network level related to the collection and sorting activities, and the previous network is retrofitted.

Keywords: Supply Chain, design, optimization, recovery network, EEE

1 Introduction

The electric and electronic equipment waste (WEEE) has been a major concern all over the world (Widmer et al., 2005). After use, some of these products are still valuable, such as personal computers that may have up to 4 g of gold. For some years now, these products have been collected and materials have been recycled, mostly in low income countries (Hilty, 2005). However, until very recently, tonnes of other equipments, full of hazardous materials, were sent to landfills causing severe environmental problems. For instance, consumer electronic equipment, such as televisions and radios, while being very hard to disassembly, contain only small amount of precious materials (Cui and Forssberg, 2003). In order to minimize this negative environment impact several legal measures have been taken to force producers to take-back and recover EEE: the EU directive for WEEE (Directive 2002/96/EC), the Japanese law for the recycling of home appliances [11], the Chinese RoHs [3], the California RoHs [1], among others.

In Europe, some countries started creating their WEEE systems by the end of the 90s. After the 2002 EU directive, all member states had to establish their own recovery program for WEEE. The created EEE European recovery systems vary in terms of structure. Some countries developed a nationwide system managed by a non-profit organization where a fee is added to the selling price of a new product (L'Eglise et al., 2000; El-Kretsen, 2006). Others established two systems that manage different categories of EEE (Renningen, 2005). While, for instance, in Spain, several foundations and companies have both a nationwide system and systems that cover just some municipalities (Queiruga et al., 2008). This EU directive was transposed to the Portuguese legislation in 2004, and December 2006 was set up as the legal dead-line to meet EEE recovery targets [5]. An organization named Amb3e, whose mission is to design and manage this recovery network, was set up by a group of EEE.

The design of such network systems is a challenge that academia has been addressing. Some works have been published where different perspectives and methodologies were studied. In this work, we focus our attention on models developed specifically for designing recovery systems.

Chan et al. (2006) developed a MILP model for the design of a WEEE collection network in China, based on a capacitated warehouse location model. Since China has very few WEEE recycling industries, no exact data is available to test the model.

Therefore, Chan et al. applied the model to an example inspired on a Chinese province data.

Salema (2007) studied the location for sorting centres in Portugal. A model was developed to design a recovery system that covered the entire country. A network structure was proposed together with a tactical planning in terms of storage and recycling activities.

Queiruga et al., in 2008, studied the best location for EEE recycling plants in Spain. This study was conducted for one of the Spanish organizations, which has a nationwide system that collects products from all WEEE categories. The authors have defined this as a multi-criteria problem, where three major criteria were chosen: economical, infrastructural and legal. The primary objective of this study was to propose a set of good alternatives for potential locations and not an optimal structure in terms of recycling plans.

The Portuguese network was implemented in 2007 and has now 71 sorting centres. In this paper, the model developed in Salema (2007) is used to retrofit the existing network Furthermore, since Amb3e is considering the introduction of a new kind of facility into the network (collecting facilities), the previous model is extended to account for it. A preliminary study will be presented and an analysis of the best locations will be given.

The paper is organized as follows. First, in the next section, the context of this case study is described, followed by the retrofitted network results (section 3). In section 4, the new facility is added to the network. The model is summarized and preliminary results are given and discussed. Lastly, some final remarks are drawn and future work proposed.

2 Case study description

Amb3e aimed at choosing locations for sorting centres that covered most of the Portuguese territory. At a first stage of the network design, Amb3e concentrated its efforts in selecting adequate locations for sorting centres in order to have a balanced network. These centres sent the material to two recycling facilities, currently operating in Portugal. One is dedicated to lighting equipment and the other recycled the remaining products. None of these facilities (sorting centres or recycling facilities) belong to the organization. These are private entities that entered contractual agreements with Amb3e.

Based on the above description, three different entities integrated the system: WEEE sources, sorting centres and recycling facilities. Sources of electronic waste can be of different nature: individual consumers, offices, companies and municipalities that collect waste, manufacturers or their representatives that take back old equipments when selling new ones. Sources of WEEE were grouped by geographical locations according to municipalities and so, 278 locations were considered as possible WEEE sources. The Portuguese household waste organizations group these 278 locations into 30 larger intervention areas.

The model proposed in Salema (2007) designed and planned this network. The model considered WEEE sources and recycling facilities as fixed locations, and the main decision was the location of the sorting centres. These receive the WEEE sent by sources, sort it according to five categories defined by the organization (large and small equipments, televisions and monitors, cooling equipments and lighting equipment) and send it to the recycling facilities.

Several analyses were made in order to gain insight concerning the best location of sorting centres. Two different time horizons were considered: one year and five years.

For each scenario, two runs were performed considering capacitated or uncapacitated centres.

Nowadays, the network in operation has 71 centres located in 64 municipalities. No other recycling facility integrates the system, which means that all flows, with the exception of lighting equipments, are sent to Tondela. The location of this facility has a major impact on the network structure since 98,5% of collected products are sent there.

Some of the existing locations were not part of the optimal solution (presented in Salema, 2007) and are installed in areas where small amounts of WEEE are estimated to be available. One of the reasons for these centres to be opened is that they belong to local household waste associations and due to contractual agreements, all centres belonging to the waste collection association enter the WEEE system.

In the next section, the network will be retrofitted considering these 64 municipalities as fixed locations.

3 Retrofitted network

The 64 municipalities with operating centres are shown in Figure 1 (white dots). Seven of these municipalities have two centres operating (larger white dots).

In order to study the retrofitting of the existing network, the model proposed in Salema (2007) was used, where the currently operating sorting centres are introduced as fixed locations and the remaining 214 are left as possible locations. For the operating centres neither a maximum nor a minimum capacity limits were imposed. This option is two-fold: firstly, if the minimum capacity set by the organization was imposed, the model would be infeasible, since there is no WEEE available to assure this minimum processing capacity; secondly, it allows an analysis of processed volumes by the operating centres.

Figure 1: Retrofitted network.

In the retrofitted network, 23 new locations were chosen in addition to the 64 fixed previously. Figure 1 shows both new (red dots) and existing centres. A first analysis reveals that more centres are required in the most populated regions of Portugal: Lisboa and Porto metropolitan areas and in the Algarve. Some other districts are already sufficiently covered, since no new location was chosen.

Note that in some locations a white dot overlaps the darker one. This means that, although there are centres operating in those locations, if the maximum capacity limited is imposed, they are short numbered.

This is confirmed by a more detailed analysis to the processed volumes. This analysis shows that, if the maximum limit is imposed, 53 municipalities (out of 64) have already enough centres operating. Five of the remaining 11 municipalities need a considerable number of new centres. In terms of the new locations, sixteen (out of 22) need one or two centres, while the remaining seven should count with several new facilities.

Thirty nine (out of 64) operating centres work under the minimum capacity set by the organization. These centres are mostly located in east part of the country and in the south.

In terms of uncollected WEEE, only four out of the 278 sources have no collection. Although the objective function is penalized if any WEEE is left uncollected, this term is almost negligible, since these municipalities have a small number of inhabitants.

Regarding the stock policy, stocks grow over the time horizon (see Figure 2). However, these are fictitious stocks. They are created because the time horizon comes to an end, which means that there are no more products to be collected afterwards. In a real environment where the time horizon is not finite, a zero stock policy would be follow.

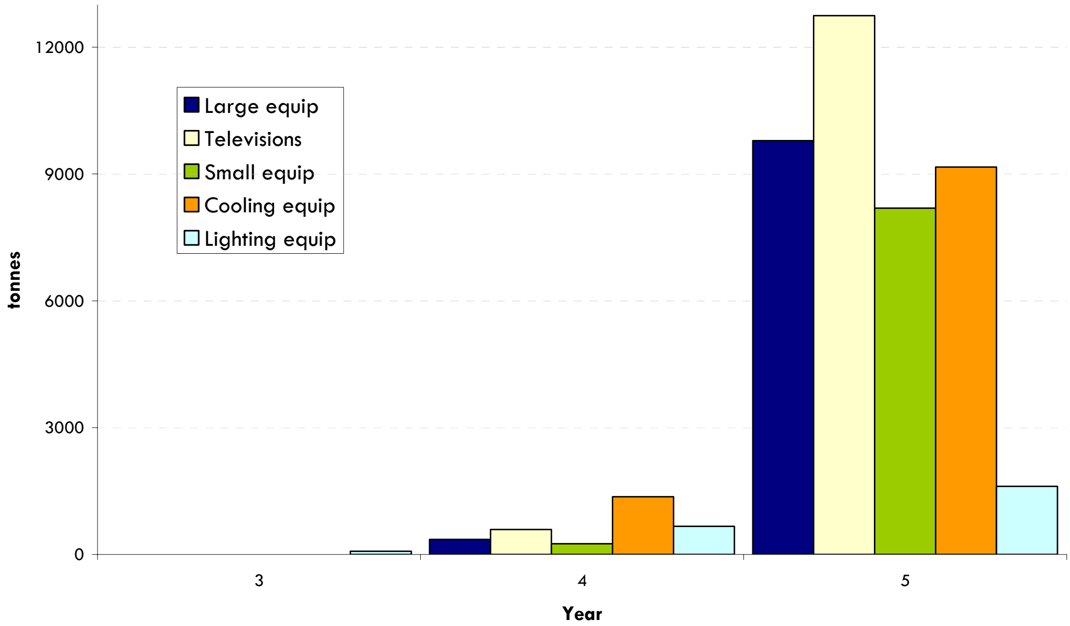

Figure 2: Total stock levels in sorting centres.

Figure 3 shows the cost structure behind this network. Transportation and recycling costs represent 83% of the network total cost. These are followed by stock costs which are 13%. Operational costs refer to collection and sorting operations, representing only 4% of the total cost.

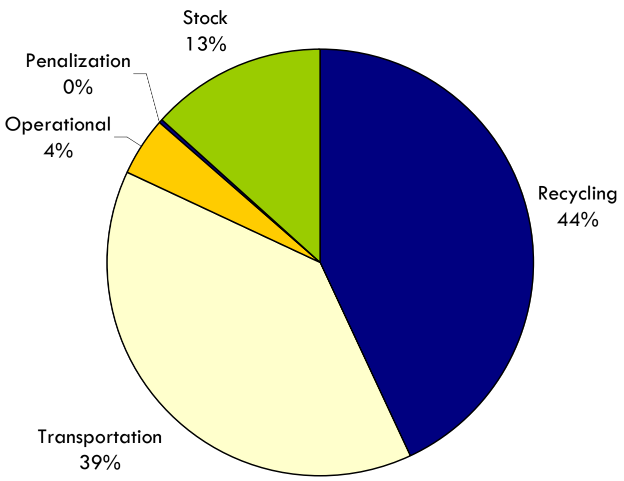

Figure 3: Cost of the retrofitted network.

4 A new network level

In 2007 new network conditions arose caused by the fact that companies within the network wished to act as simple collecting centres. Consequently, it was required to re-structure the existing network through the introduction of an extra level (collecting). A collecting facility was therefore integrated into the network and a new structure defined (Figure 4). The major difference to Salema (2007) work is that WEEE sources can send products either to collections centres or directly to sorting centres.

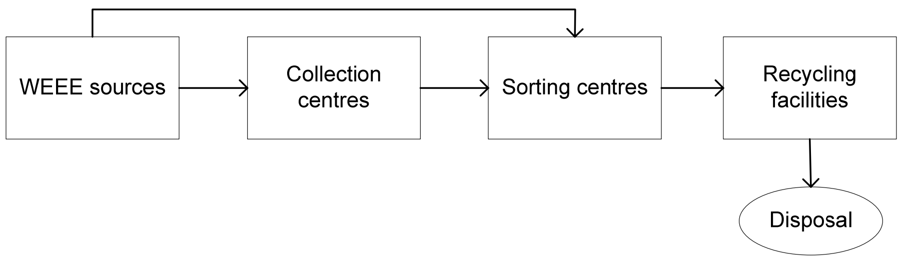

Figure 4: Schematic representation of the WEEE recovery network.

Since there are enough centres in some districts, we will perform this study only in those areas where more centres are required (Lisboa and Porto districts).

In terms of the problem context, it should be mentioned that Portuguese administration has a three level structure: Government (central), municipalities and “freguesias”.

For the design of the recovery network with the new structure, the freguesia was chosen rather than municipality. This option is two-fold: firstly, these new collection centres should be smaller than sorting centres; secondly, some municipalities are already served by sorting centres (as shown above), therefore it makes no sense to open additional ones at these locations.

The analysis presented in this work is restricted to the Lisboa district, which is an area where a large number of centres are needed. Lisboa district has 16 municipalities and 221 freguesias, and the main decision concerns the location of collection and sorting centres. Since six sorting centres are currently in operation, their locations are fixed, as well as those for the WEEE sources and the recycling facilities. In short, there are 221 different WEEE sources and possible locations for collection centres, 10 possible locations for sorting centres, 6 operating sorting centres and 2 recycling facilities.

Maximum and minimum limits were imposed on processing and/or storage capacity both for collection and sorting centres, and also for maximum distances between sources and centres. Within the latter, it should be noted that sorting centres have a larger intervention area than collection centres.

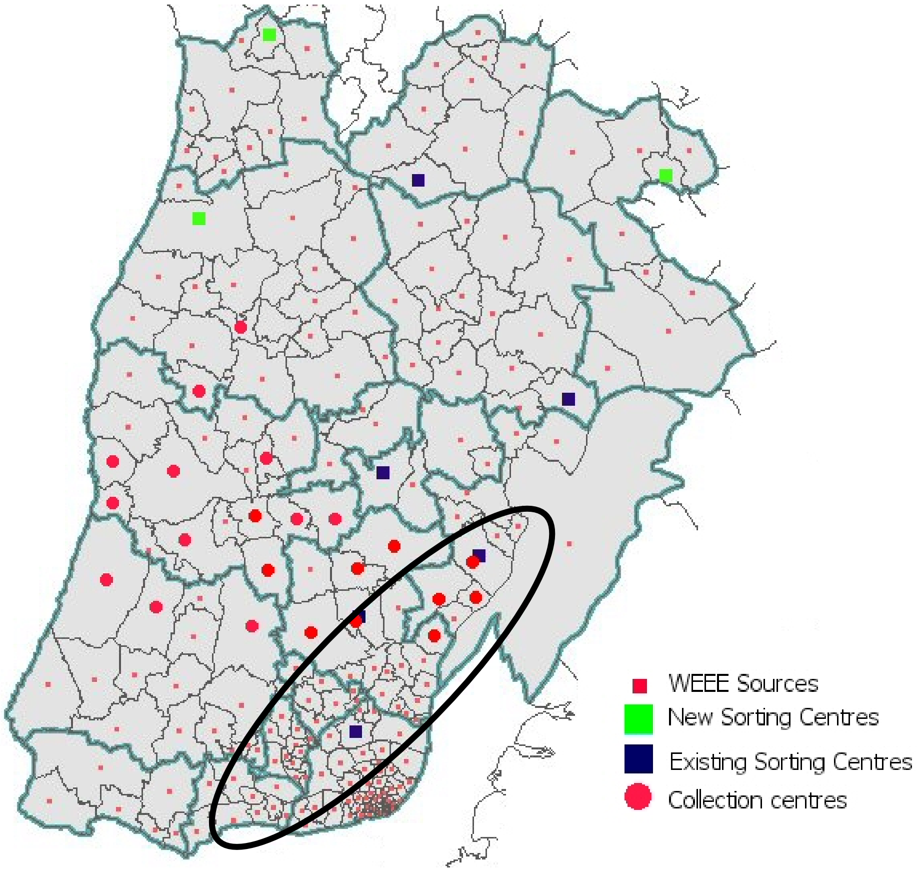

Figure 5: Recovery network with collections and sorting facilities.

Results

All 221 sources are fully served by 22 collection centres and 9 sorting centres Three locations were chosen to open new sorting centres. The network structure shown in Figure 5 is justified by the location of the major recycling facility in Tondela, as mentioned above. According to the maximum distances set by the organization, the location of new sorting centres, in the north area of the district, is such that it minimizes the outbound transportation costs. On the other hand, the maximum distance between collection centres and WEEE sources is shorter, and therefore, the locations chosen are the ones that simultaneously minimize the transportation cost and assure than the largest area in terms of population is covered (marked in the figure). Since there is no fixed cost associated with the choice of locations and the minimum limit in collection volume is rather small, there are a large number of locations, albeit some of them exhibiting small processing volumes (see Figure 6).

A detailed analysis of processing volumes shows that centres inside the marked area are the largest, that five out of nine sorting centres work at full capacity, while four of them are located in the northern part of the district and also that the two centres located near Lisbon municipalities are the smallest in terms of processed volume. This confirms the previous observation concerning the location of the recycling facility.

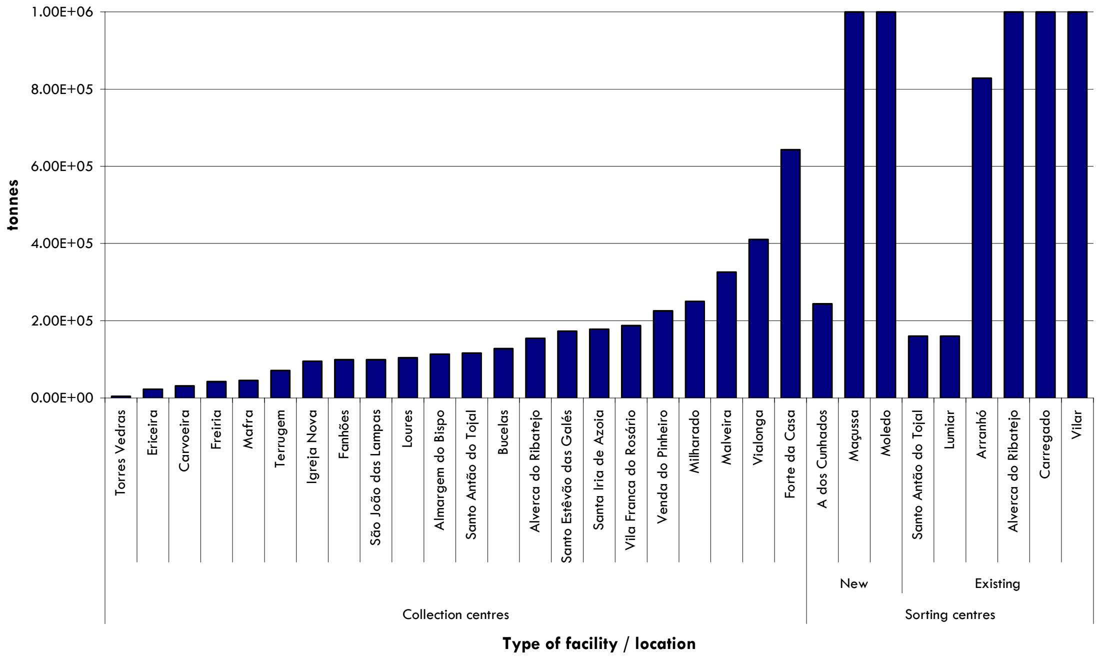

Figure 6: Annual processed volume by centre.

The volume analysis also shows that the collection centres located in the western area are the smallest, which is a further confirmation of the effect of the no fixed costs policy.

This preliminary study also shows that a sensitive analysis is needed for parameters such as maximum distance and minimum processing volumes, in order to adequately reassess Amb3e estimated costs.

In terms of costs, recycling and transportation represent about 97% of the total network cost (Figure 7). As an alternative to an annual fixed cost paid to each centre, Ambe3 and the centres agreed on a unitary cost per processed tonne. These are shown in Figure 7 as collection and sorting centres costs, and represent only 3% of the total cost.

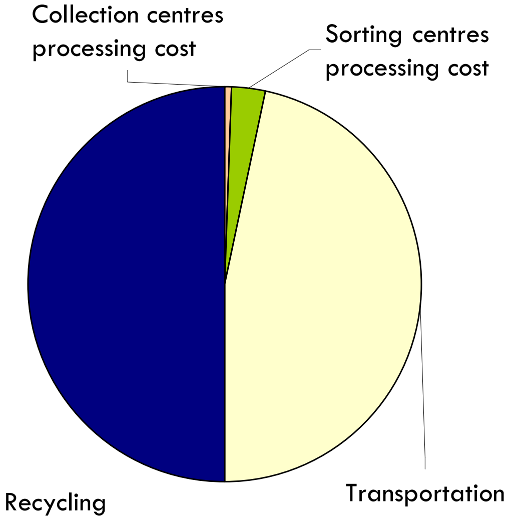

Figure 7: Network costs.

The cost function also takes into account storage and a penalization cost if some EEE is left uncollected in any source. Neither of these costs are incurred in this case since no storage is made and WEEE is totally collected at sources. Again, all unit costs used were based on estimations provided by Amb3e. Since the network was implemented during 2007, these values should be reviewed and a sensitivity analysis performed particularly in relation to recycling and transportation costs.

Lastly, Table 1 shows the computational results of the model. The model has a large number of variables and constraints. It was solved to optimality in about 16 minutes of CPU. The relaxation value is of very good quality when compared to the optimal value.

Table 1: Computational results

Total variables	Binary variables	Total constraints	Optimality margin	CPU's (sec.)	Relaxation value	Obj. function value (m.u.)
625 892	231	840 379	0%	985	3349005796	3349057253

5 Conclusions

The Portuguese recovery network for WEEE emerged during 2007. Previous work developed by the authors was presented and a retrofit network design performed. One major conclusion, regarding the existent operational network, it is the lack of facilities in some highly populated districts and therefore the need to retrofit the network.

Due to new network conditions, a new structure was studied where a new type of entity was considered (collecting centres). The modelling framework previously defined in Salema et al. (2008b) is used and a generalised model is developed. Lisboa district is studied and new locations for collection and sorting centres are proposed.

As future work this study will be extended to the Porto district, which presents equally a lack of collection/sorting centres.

The sustainability of the designed networks will also to be explored, where the network is to be designed considering simultaneously the minimization of costs and environmental impacts. The environmental impact of recycling WEEE is certainly an important issue that should not be ignored, as the discussion on tradeoffs between recycling and disposal, undertaken by several authors (Hischier et al., 2005), seems to point out.

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References

[1] CDTSC - California Department of Toxic Substances Control, http://www.dtsc.ca.gov/HazardousWaste/EWaste/ (last accessed February 2008).

[2] Chang, X.Y., Huo, J.Z., and Chen, S. (2006). Study on integrated logistics network model and network design for waste electrical and electronic equipment. In *2006 Ieee International Conference on Service Operations and Logistics, and Informatics*, pp. 654-658.

[3] China RoHS, http://www.chinarohs.com/ (last accessed February 2008).

[4] Cui, J.R., and Forssberg, E. (2003). Mechanical recycling of waste electric and electronic equipment: a review. *Journal of Hazardous Materials 99(3)*, 243-263.

[5] Decreto-lei no 230/2004 of Portuguese Government of 10 December 2004 on Waste Electric and Electronic Equipment.

[6] Directive 2002/96/EC of the European Parliament and of the Council of 27 January 2003 on Waste Electrical and Electronic Equipment.

[7] El-Kretsen (2006). Annual report.

[8] Hilty, L.M. (2005). Electronic waste - an emerging risk? *Environmental Impact Assessment Review 25(5)*, 431-435.

[9] Hischier, R., Wager, P., and Gauglhofer, J. (2005). Does WEEE recycling make sense from an environmental perspective? The environmental impacts of the Swiss take-back and recycling systems for waste electrical and electronic equipment (WEEE). *Environmental Impact Assessment Review 25(5)*, 525-539.

[10] L'Eglise, T., De Lit, P., Delchambre, A., and Raucent, B.A. (2000). Recycling of electric and electronic end-of-life devices: economical assessment study in Brussels, Belgium. *Proceedings of the 2000 IEEE International Symposium on Electronics and the Environment*, 149-154.

[11] PERA (2006). Waste electrical and electronic equipment (WEEE): innovating novel recovery and recycling technologies in Japan. Department of Trade and Industry, UK.

[12] Queiruga, D., Walther, G., Gonzalez-Benito, J., and Spengler, T. (2008). Evaluation of sites for the location of WEEE recycling plants in Spain. *Waste Management 28(1)*, 181-190.

[13] Renningen, B. (2005). Competitors together in PRO (Producers Responsibility Organisation) - a case study of the PRO-system in Norway. *Proceedings of the 2005 IEEE International Symposium on Electronics and the Environment*, 45-48.

[14] Salema, M.I. (2007). Design and planning of closed-loop supply chains. PhD Thesis, Instituto Superior Técnico, Universidade Técnica de Lisboa, Lisboa.

[15] Salema, M., Barbosa-Povoa, A., and Novais, A.Q. (2008a). Design of a recovery network in Portugal: the electric and electronic equipment case. *International Engineering Management Conference - Europe 2008*, IEEE. Estoril, Portugal.

[16] Salema, M.I., Barbosa-Povoa, A.P., and Novais, A.Q. (2008b). Simultaneous design and planning of supply chains with reverse flows: a generic modelling framework. *European Journal of Operational Research*. (submitted)

[17] Widmer, R., Oswald-Krapf, H., Sinha-Khetriwal, D., Schnellmann, M., and Boni, H. (2005). Global perspectives on e-waste. *Environmental Impact Assessment Review 25(5)*, 436-458.